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Study of radon exhalation in soil and air concentrations at Mysore

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Abstract . The radon exhalation rate from soil ranged from 5.12 to 9.60 mBq $m^{-2}.s^{-1}$ with a median of 7.72 mBq m^{-2} s^{-1}, and air concentrations ranged from 3.85 to 11.63 $Bq.m^{-3}$ with median value of 6.48 Bq m^{-3}. The daughter product activity ranged from 0.20 to 1.32 mWL with a median value of 0.66 mWL. From the measured mean activity of radon daughters, the dose to the population of Mysore was found to be 0.14 mSv per year. The observed low exhalation rates and concentrations of radon and its daughter products are attributed to low background concentration of Radium-226 in the area where studies have been carried out. Concentrations of radon and its daughter products in air and in some dwellings at a few locations at Mysore city have been also measured.

Relations between the radon exhalation rate, concentration of radon and its daughter products in air with different meteorological parameters such as temperature, atmospheric pressure, wind velocity, wind direction, relative humidity and rainfall have been studied. Diurnal and seasonal variations have been measured. Porosity of the soil samples has been determined. Higher radon concentrations have been observed during nights and early morning hours.

Keywords Radon exhalation, radon concentration in air, meteorological parameters

PACS Nos. : 89.60.+x, 92.60.Ry, 92.60.Jq.

1. Introduction

Radium-226 present in soil and rocks is the primary source of radon outdoors and inside buildings. Radon and its daughter products are ubiquitous in the environment and hence radon in soil and air can be studied to understand such diverse processes as earthquakes, eruptive and noneruptive volcanoes [1,2] ground water transport and air mixing in the atmosphere [3,4]. The half life of radon (3.82 days) is long enough to permit its diffusion from soil and building materials to the ambient atmosphere. The concentrations of radon and its daughter products are generally higher inside the dwellings than outside. It has now been established that health risk to humans due to exposure to indoor radon and decay products may not always be insignificant [5]. Such risk may exist in small groups of houses depending on construction features and soil characteristics. To obtain an accurate estimate of radon related lung cancer risk and to plan proper control measures, the population dose in different regions of the world must be known [6]. The present paper gives the results of the estimation of radon exhalation from soil, and concentrations of radon and its decay products in air inside as well as outside buildings. The influence of meteorological parameters such as temperature, relative humidity, atmospheric pressure, wind velocity and direction, rainfall and the soil parameters such as porosity, and nature of soil on exhalation rate and air concentrations also have been studied. Radon exhalation from soil and concentrations of radon in indoor and outdoor air have been measured elsewhere [6,7]. In this paper, we have studied radon exhalation rate at a fixed location in Mysore. Measurements were made using "Low Level Radon Detection System (LLRDS)".

2. Methodology

Radon concentration :

Estimation of radon concentration in air was made using the LLRDS. Measurement procedure described elsewhere [8] was followed. The procedure consists of collecting the air sample in a chamber and exposing a circular metallic (aluminium or stainless steel) disc of 50 mm diameter to the air containing radon inside the collection chamber. The disc is maintained at a negative potential of -800V with respect to the body of the chamber, which is grounded. Radon decay products, as they are produced, are known to be positively charged. The decay products formed inside the chamber get attracted to the disc which is negatively charged. The decay products collection time is 75 minutes. The disc is then taken out and counted for alpha activity typically for about 5000 sec. Radon concentration in the chamber is given by

$$Rn\,(\mathrm{Bq.m^{-3}}) = \frac{1000C}{E.F.V_1.Z}, \tag{1}$$

where C = The net total number of counts observed during the counting period,

E = The alpha counting efficiency (0.26%),

F = The efficiency of collection of RaA atoms on the disc and is empirically related to humidity by

$F = 0.9\,\{1 - \exp(0.039H - 4.118)\}$, where

H = Relative humidity (%) and

Z = The theoretical correction factor for build up of radon daughter atoms on the disc and decay during exposure and counting period,

V_1 = The volume of LLRDS chamber (liters).

3. Radon daughters' activity

The concentrations of radon daughters were measured using Kusnetz's method [9]. Air was drawn through a glass fibre filter paper by means of a suction pump at a known flow rate. The decay products of radon in air get deposited on the filter paper. The filter paper was then alpha counted after a specific time delay. Radon daughter concentration (in working level unit) was calculated using the Kusnetz's [9] equation modified by Raghavayya [10]. The original equation was modified to include a correction factor F for the sampling time and counting period. The expression used to calculate the radon daughter concentration is

$$RD(WL) = \frac{C}{E.L.F.(T,t)}, \tag{2}$$

where C = The count rate,

E = Efficiency of alpha counting system (0.26%),

L = Sampling rate in liter per minute (LPM),

$F(T,t)$ = Working level factor corresponding to a sampling time T min and counting delay of t min.

4. Radon exhalation from soil

The procedure for the estimation of exhalation rate from the soil briefly consists of the following steps :

1) Accumulation of air exhaled by ground,
2) sample transfer,
3) radon estimation,
4) Calculation of exhalation rate.

The experimental set up is as shown in Figure 1. It consists of a cylindrical metallic vessel of diameter 420 mm and height 270 mm with its open end buried to a depth of 150 mm at

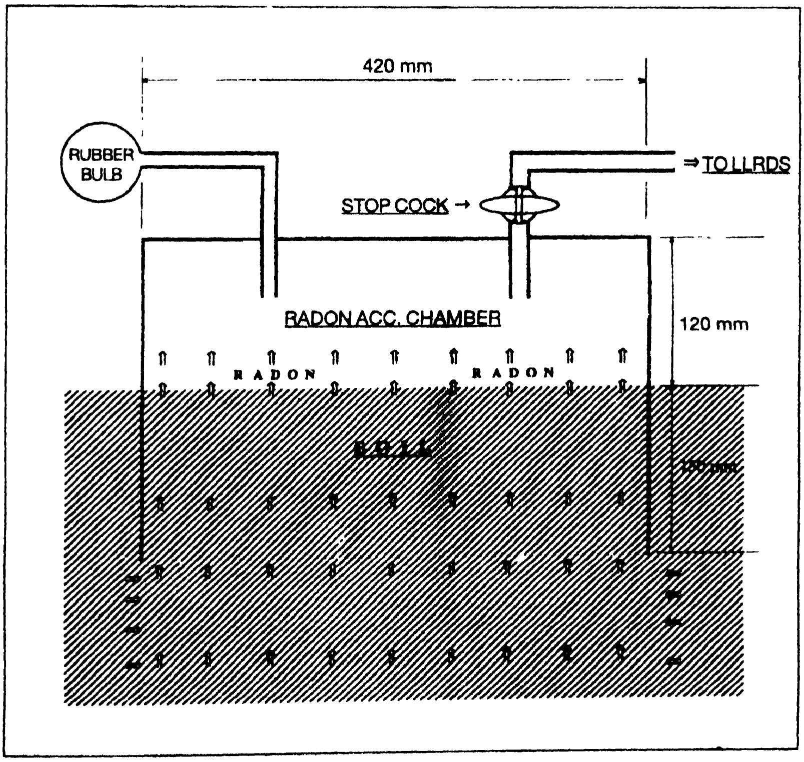

Figure 1. Schematic of experimental set up ACC-Accumulation chamber.

the selected location. The effective volume of the chamber is 16.6 litres. On the top of the chamber, two openings are provided, one for connecting a hard rubber bulb which is used for mixing the air uniformly in the collection chamber and the other for transferring the air from collection chamber to the LLRDS. Radon exhaled from soil gets collected in the chamber. After allowing accumulation for about an hour, a sample of air from the chamber was drawn into the LLRDS. The one hour duration for collection was chosen after a series of preliminary experiments with varying collection periods. The collection for one hour was found to be adequate for accurate estimation purpose for this site. There after radon concentration in the LLRDS was estimated as described earlier [8]. The exhalation rate from the soil is calculated from the estimated radon concentration using the following equation.

$$J\,(\mathrm{Bq.m^{-2}.s^{-1}}) = \frac{(V+v).Rv.n}{A(1-\exp(-nt))} \tag{3}$$

where

$J\,(\mathrm{Bq.m^{-2}.s^{-1}})$	Exhalation rate of radon from soil,
$A\,(\mathrm{m^2})$	Exhalation area,
$V(\mathrm{m^3})$	Volume of the accumulation chamber,
$v(\mathrm{m^3})$	Volume of the LLRDS,
$n(\mathrm{s^{-1}})$	Decay constant of radon,
$Rv\,(\mathrm{Bq.m^{-3}})$	Concentration of radon estimated as described above (eq.1),
t (sec)	Duration of radon accumulation.

To study diurnal variation of radon and daughter concentration, measurements were carried out at 2 hourly intervals. Humidity, ground temperature, atmospheric pressure, and rainfall were recorded. Measurements were carried out thrice a day and 4 days in a month over

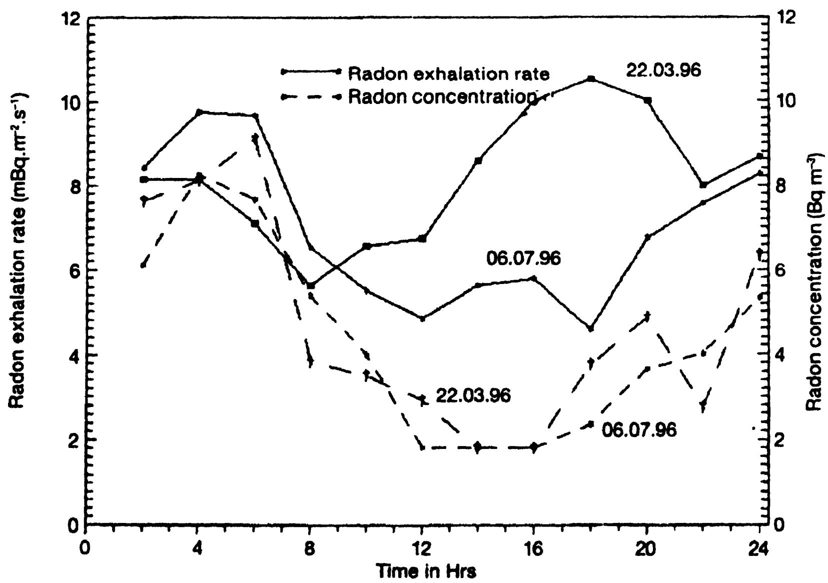

Figure 2. Radon exhalation and its air concentration (diurnal variations).

a period of one year. The meteorological parameters such as wind velocity and wind direction were monitored over the period of the measurements.

5. Results

Results of the measurements are summarized in Table 1 to 4 and also presented in Figure 2 to 5. Radon and decay products concentrations in dwellings are given in Table 5. The rate of Radon exhalation from soil varied from 5.12 to 9.60 $mBq.m^{-2}.s^{-1}$ with a median value 7.72 $mBq.m^{-2}s^{-1}$. Atmospheric radon concentration varied from 3.85 to 11.63 $Bq.m^{-3}$ with a median value 6.48 $Bq.m^{-3}$ The activity of radon daughter in air ranged from 0.20 to 1.32 mWL and in dwellings at a few locations in Mysore city the variation was from 0.35 to 1.95 mWL.

Table 1. Radon exhalation and concentration values with meteorological parameters [summer season (dry conditions) water content in soil is 2 5%]

22.3.1996

Time of day Hrs	Radon exhalation $mBq.m^{-2}.s^{-1}$	Temperature difference °C	Radon concentration $mBq.m^{-2}.s^{-1}$	Radon daughter products mWL	Atmospheric Pressure mms of mercury	Humidity in %	Wind velocity mt/sec
02	8.15	-3.5	7 62	0.86	701.00	63	0.40
04	8.15	-4.5	8 12	0.85	700 20	63	calm
06	7.12	-4.5	9.10	0.74	701 30	65	calm
08	5.62	-3 8	3 82	0.42	702 00	56	2.15
10	6 58	4 0	3 50	0.35	702.30	48	2.65
12	6.75	4.5	2.90	0.24	702.20	42	1.98
14	8 58	2.5	1 80	0 19	700 00	38	1 62
16	9.98	-0 5	1.80	0.18	699.80	20	2 16
18	10.50	-6.1	3.75	0.32	699.40	23	2.00
20	10.00	-5.3	4.86	0.61	700.05	45	1.85
22	8.00	-5 9	2 74	0 55	701.50	51	1.20
24	8.65	-6 0	6 36	0.80	701.40	51	calm*
06.07.96—water-content-in soil-is 30%-under wet-conditions-							
02	8.42	-3.6	6.10	0.65	701.20	80	0.30
04	9.75	-4.2	8.26	0.86	701.60	89	clam*
06	9.68	-4.2	7 66	0.86	702.10	89	1.1
08	6 55	-1.5	5 38	0 31	702.26	80	3.26
10	5.50	3.2	4 00	0.15	702.36	72	5.98
12	4.83	5.0	1 80	0.11	700.10	55	7.65
14	5.62	4.2	1.80	0 09	699 40	50	6.92
16	5.78	2.1	1.80	0.12	699.10	47	7.12
18	4.58	-1.8	2.35	0 26	698.45	53	5.53
20	6.75	-3.3	3.65	0.29	700.00	71	3.25
22	7.56	-2.7	4.00	0.48	700.40	75	1.50
24	8.26	-3.0	5.32	0.56	700.80	78	0.50

' When the wind velocity was less than 0.1-mps it is called calm.

Diurnal variations :

From the data given in Tables 1 and 2 and analyses carried out as shown in Figure 2 and 3 the following observations can be made.

Table 2. Diurnal variation of radon exhalation rate with variation of temperature gradient (22.03.1996 and 06.07.1996)

	Wet condition water content in soil 30%				Dry condition water content in soil 2.5%			
Time of day	Radon exhalation rate	Ground surface temperature	Ground temperature at depth 15 cm	Temp. diff.	Radon exhalation rate	Ground surface temperature	Ground temperature at depth 15 cm	Temp. diff.
Hrs	$mBq.m^{-2}.s^{-1}$	°C	°C	°C	$mBq.m^{-2}s^{-1}$	°C	°C	°C
02	8 42	21.2	24 8	-3 6	8.15	27.5	31.0	-3.5
04	8 95	20	24.2	-4 2	8.15	26.5	31.0	-4.5
06	8.78	19 8	24	-4 2	7.12	26.5	31.0	-4.5
08	6.55	22 5	24	-1 5	5.62	28 2	32	-3.8
10	5.50	29.5	26.3	3 2	6.58	37	33	4 0
12	4.83	33.5	28.5	5 0	6 75	39	34 5	4.5
14	5.62	34	29.8	4.2	8.58	42	39.5	2.5
16	5.78	32	30	2.0	9 98	42	41 5	0.5
18	4 58	27.2	29	-1.8	10.5	32 5	38.6	-6.1
20	6 75	24.7	28	-3 3	10.0	30 7	36 0	-5 3
22	7.56	23.7	26 4	-2 7	8 0	28.6	34.5	-5.9
24	8.25	22.5	25.5	-3.0	8.65	28.0	34.0	-6 0

An appreciable variation in the radon exhalation rates has been observed during variations occurring in temperature difference between ground at 15 cms depth and surface –

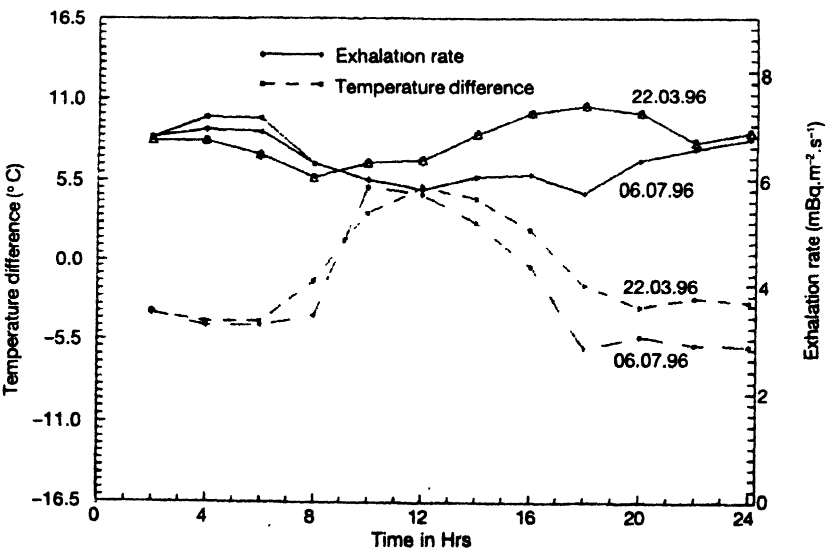

Figure 3. Diurnal variation of radon exhalation rate with variation of temperature gradient.

air interface. Under wet conditions, an increase in the exhalation rate has been observed during night and early morning. During these periods, the ground has been found to be warmer than the surface air (Table 2).

Table 3. Radon exhalation and concentration, monthly averages 1996-97

Months	Radon exhalation rate $mBq.m^{-2}.s^{-1}$	Radon concentration $Bq.m^{-3}$	Radon daughter products mWL	Average humidity %	Average ground temperature °C	Average atmospheric pressure mm	Average wind velocity m/sec	Total rain fall mm
March 96	7 72±0.26	5 3±0.21	0.66±0.08	50.66	30 8	702 38	2.84	-
April 96	7 78±2 8	4.32±0.26	0 31±0 11	57 5	34.62	700 80	3.7	61
May 96	7 4±1 8	5 23±1 0	0 45± 07	56 00	32 6	700 97	4 8	10
June 96	6.55±2.58	4.59±1.3	0 22±.09	68.42	28 17	700 29	5 6	110
July 96	5 8±1 44	4 52±1.07	0.20± 06	71 57	25 65	699 62	4 5	40
Aug 96	5 12±2 18	4.02±1 41	0 25±0 1	73 00	24 20	699 78	4 2	91
Sept 96	5.13±2.0	3 93±1.2	0 26±0 1	72.85	24.8	700 51	3 8	155
Oct 96	5 42±1 7	4 25±1 2	0 58±0 1	72.25	24.82	701 07	3 3	90
Nov 96	6 07± 27	8 23± 15	0.89± 34	59 33	24 90	702 78	2 2	-
Dec 96	7.16±.52	11.63± 8	1.32± 14	57.35	24.86	703 26	1.88	-
Jan 97	8.93±.85	7.22±.26	1 09± 16	46.45	24.27	702 85	1.92	-
Feb 97	9 60±.65	6 48± 74	0 49± 05	54 00	27 50	702 50	2.13	-

In wet conditions, it is seen that the rate of exhalation decreases during 0800–1800 hrs where as in summer the rate of exhalation decreases only between 0800–1200 hrs, (Table 1).

In dry condition between 1400–1600 hrs, ground temperature gradually increases and reaches maximum. It has been observed that between 1800–2000 hrs during dry condition, the ground temperature is higher than the ground surface temperature (Table 2). During this time, the exhalation rate has been observed to be higher. Exhalation rate is almost constant during the night and early morning hours.

Table 4. Effect of rainfall on radon exhalation and its air concentrations

Date	Radon exhalation rate $mBq.m^{-2} s^{-1}$	Radon concentration $Bq.m^{-3}$	Radon daughter activity mWL	Rainfall mm
16 5.96	9 22	6 96	0.95	-
25.5 96	5 58	4 22	0 56	15
31.5.96	9 65	5 83	0 65	-
03.6.96	2 76	3 26	0.37	70
04.6 96	8 35	4 58	0.45	-
08.6.96	7 50	5.33	0.62	-
12.6.96	3.41	2 78	0.25	40
15.6.96	9.86	4.65	0.64	-
27.6.96	7 42	6.98	0.48	-

Table 1 shows that under certain condition, an inverse correlation between radon exhalation rate and atmospheric pressure exists and during certain other conditions, the radon exhalation rate does not correlate with atmospheric pressure.

Table 5. Concentrations of radon and its daughter products in different types of buildings.

Location	Types of buildings	Ventilation	Radon concentration $Bq.m^{-3}$	Radon Daughters concentration mWL
Ground floor	Cement flooring brick walls	good	8.25	0.45
Ground floor	Cement flooring brick walls	poor	12.58	0 93
Ground floor	Mosaic surface	good	6.35	0.35
First floor	Cement flooring brick walls	partial	10.78	0.75
First floor	Cement flooring brick walls	poor	12 65	0 68
Huts	Mud wall and mud surface	very poor	14.65	1 95

Results given in Table 1 shows the diurnal variation. Figure 2 shows that the night-time concentrations of radon and its daughter products are usually higher than day time, the maximum occurring in the early hours of the day (0400 to 0600 hrs). The existence of higher concentrations in night and early morning may be due to inversion conditions in the lower atmosphere. During inversion, air movement upwards is low. As a result, radon and its daughters are present in higher concentrations at the ground level. Fluctuations in air concentration were observed during 1800 to 2200 hrs. After sunrise, the convective current of the atmosphere transports the radon gas and short lived daughter products to the higher atmospheric layers, resulting in a

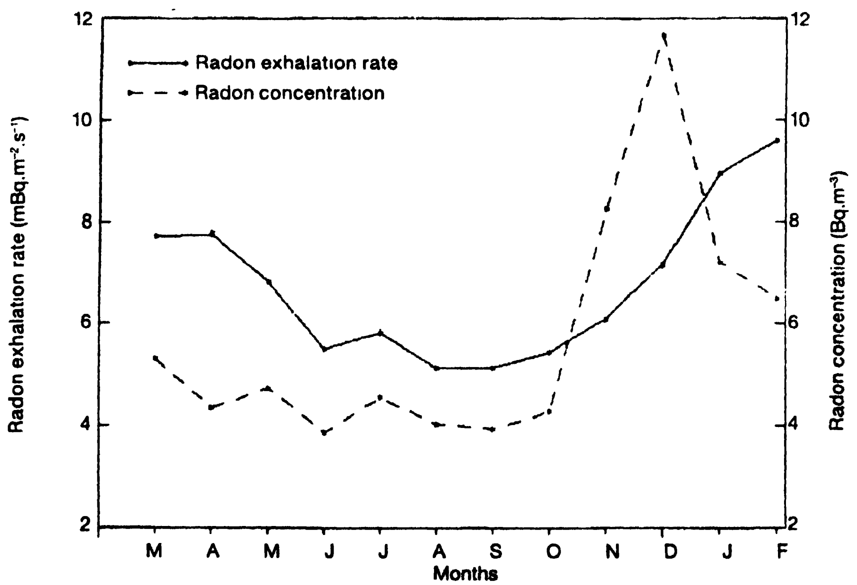

Figure 4. Rate of radon exhalation from soil and its air concentration, monthly average (seasonal variations).

decrease in concentrations at lower levels. The amount of radon gas and daughter products near ground level increase resulting in the higher concentrations observed during night. The cycle then repeats. Thus, the concentrations in the nights are higher than those during day time.

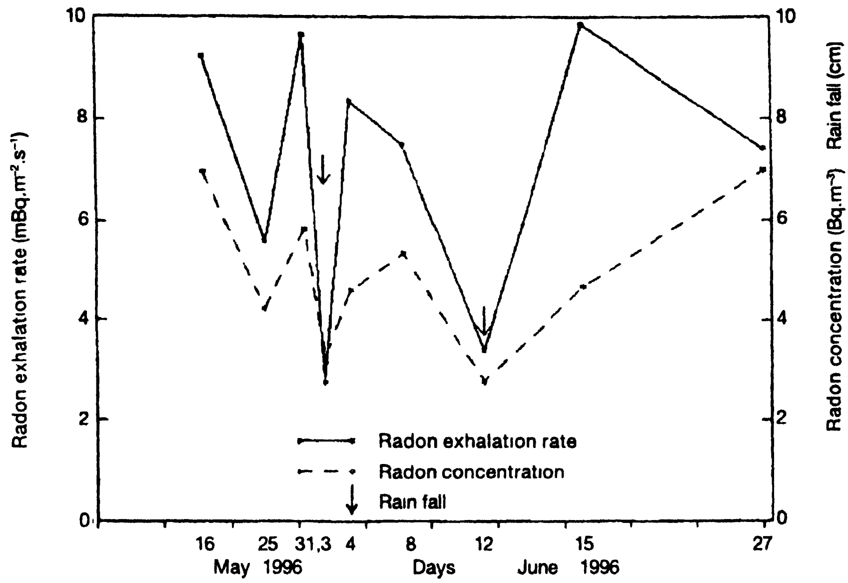

Figure 5. Effect of rainfall on radon exhalation and air concentration.

Seasonal variations :

Seasonal variations of radon exhalation and air concentrations are given in Table 3 and Figure 4. An annual maximum of radon and its daughters' concentrations occurred during November to February and minimum during March to October. The concentration of radon and daughters at Mysore is higher during winter. This could be due to temperature inversion which can generally be expected to be frequent in winter [11, 12]. The concentrations gradually decrease and is lowest in September. Turbulent transfer in the summer causes low radon and daughter product concentrations at lower atmosphere [12]. The decrease of radon concentration in rainy season has been observed to be due to high wind velocity, and decrease in the exhalation of radon from soil. During rainy season, soil becomes saturated with water [12, 13]. From Table 3 and Figure 4, it can be seen that exhalation rate is maximum during summer and gradually decreases in rainy season and winter. The rate of radon exhalation generally varies with the moisture content of the soil. During the winter months, exhalation rate is low and the variation is less. In general, we have noticed that during rainy season, fluctuation is more pronounced. This is due to sporadic nature of rains in Mysore. In summer, the ground temperature is high and atmospheric pressure is low, and so diffusion of radon increases.

Effect of rainfall :

Table 4 and Figure 5 show the effect of rainfall on radon exhalation and air concentrations. When the ground is wet due to rain, exhalation reduces and when precipitation is high, resulting in soaked ground condition, exhalation ceases altogether. As the moisture content of the upper layer of the soil reduces due to evaporation, the excess of radon accumulated in the soil below, gets released resulting in relatively higher radon exhalation. When the excess water has evaporated, radon exhalation also returns to normal [14]. The exhalation rate depends also on the porosity of the soil. The porosity of the soil in the location where the present measurements have been made was found to be 0.41. In the other location, the porosity was found to be 0.54. The exhalation rate (33.67 $mBq.m^{-2}.s^{-1}$) measured in later location was higher than in the former one. It is well known that the radon exhalation rate also depends on the radium content of the soil and the median value of ^{226}Ra in Mysore region 13.63 $Bq.kg^{-1}$. Which is lower than the global average of 2.96–140.6 $Bq.Kg^{-1}$, [15].

Radon in dwellings :

The radon daughter concentration measured inside dwellings at a few places in Mysore city is shown in Table 5. Radon and daughter concentration is seen to be higher in huts, than in masonry houses. Huts usually are mud walled and have no windows and have poor ventilation. Radon concentration bears an inverse correlation with ventilation. Assuming that the measurements made in a few dwellings are representative for Mysore, estimate of population dose has been made using the activity to dose conversion factor of 3.88 mSv/WLM (ICRP 1993) [16]. A median of 0.75 mWL for all the houses is taken for the purpose of calculating the dose. The dose to the population of Mysore city due to radon daughter activity works out to be 0.14 mSv per year. The calculated annual exposure for indoor radon values were less than the ICRP recommended levels [17]. The inhalation dose rate due to indoor radon for a person who lives in the Tehri Garhwal environs were reported, the mean value varies from 4.2 to 5.2 $mSv.y^{-1}$ respectively [18]. All India mean effective dose equivalent is 2.43 $mSv.y^{-1}$ and the global effective dose equivalent is 2.36 $mSv.y^{-1}$ [19].

6. Conclusions

The medians of the radon and its daughter concentrations in the atmospheric air at Mysore were found to be 6.48 $Bq.m^{-3}$ and 0.66 mWL respectively. The median values of the indoor radon and its daughter product concentrations are 10.78 $Bq.m^{-3}$ and 0.75 mWL respectively. The weighted average concentration of indoor radon, for the world population was found to be about 40 $Bq.m^{-3}$ as against about 10 $Bq.m^{-3}$ for outdoors (UNSCEAR 1993) [20]. The radon exhalation from soil in Mysore region was low (5.12 – 9.63 $mBq.m^{-2}.s^{-1}$) compared to the global average of 15 to 20 $mBq.m^{-2}.s^{-1}$ (UNSCEAR 1982) [21]. Variation in the concentration of radon caused by changes in the Rn 222 exhalation from soil, is usually smaller than the variations caused due to changes in atmospheric mixing.

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